



# **Interagency Operations Advisory Group (IOAG) on International Cooperation in Space Communications and Navigation**

**09 March 2017**

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Michael Schmidt (ESA), IOAG Chair



# Presentation Overview

\* Topic discussed in this presentation

- IOAG Organisation and Charter
- Key Work Results from the IOAG
  - IOAG core services for interoperability and cross support
  - Moving forward to Ka-bands\*
  - Moving forward to optical communications\*
  - Moving forward to Space Internetworking \*
  - Advancing the coding and modulation schemes
  - Enhancing spacecraft emergency cross support \*
  - Interoperability for Lunar/Mars space communications\*
- Lunar & Mars Space Communications – Findings & Recommendations
  - Lunar space communications architecture – the context
    - Mars space communications architecture – the context
    - Findings of Lunar space communications – Missions during 2016-2025 era
    - Findings of Mars space communications – Missions during 2016-2025 era
    - Some initial recommendations
- Potential IOAG – ISECG Cooperation



- |                     |                    |
|---------------------|--------------------|
| ASI/Italy           | CNES/France        |
| CNSA/China          | CSA/Canada         |
| DLR/Germany         | ESA/Europe         |
| FSA/Russia          | ISRO/India         |
| JAXA/Japan          | KARI/South Korea   |
| NASA/USA            | SANSA/South Africa |
| UKSA/United Kingdom |                    |



• Technology  
• Drivers

• Requirements  
for  
International  
• Space Mission  
Interoperability

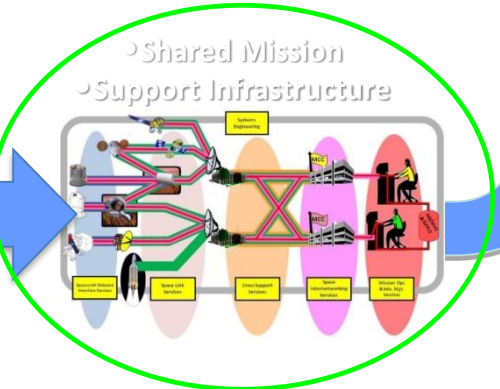


• Operations  
• Drivers



• Spectrum  
• Allocation

• Cross-Support  
• Service  
• Catalog



- ASI/Italy
- CNES/France
- CNSA/China
- CSA/Canada
- DLR/Germany
- ESA/Europe
- FSA/Russia
- INPE/Brazil
- JAXA/Japan
- NASA/USA
- UK Space Agency
- ASA/Austria
- BFSPO/Belgium
- BITTT/China
- CAS/China
- CAST/China
- CSIR/South Africa
- CSIRO/Australia
- CTA/Brazil
- DNSC/Denmark
- EUMETSAT/Europe
- EUTELSAT/Europe
- GISTDA/Thailand
- HNSC/Greece
- IKI/Russia
- ISRO/India
- KARI/Korea
- KFKI/Hungary
- MOC/Israel
- NCST/USA
- NIICT/Japan
- NOAA/USA
- NSPO/Taipei
- SSC/Sweden
- SUPARCO/Pakistan
- TsNIIMash/Russia
- TUBITAK/Turkey
- USGS/USA



# IOAG Basic Terms of Reference

- The IOAG **was chartered to be one main international body to oversee the development of collaborative, interoperable space communications and navigation services** for the benefit of all members' spaceflight missions.
- Specific instructions from the first charter included:
  - Recommend specific actions needed to facilitate cross-support of one agency's spacecraft by another agency's support facilities;
  - Study interoperability issues in particular with respect to tracking, telecommand, telemetry data acquisition systems, as well as utilization of frequency bands;
  - Maintain an effective liaison to CCSDS and SFCG and make recommendations for standards development.
  - Draw on the technical work already completed by other organizations developing standards or regulations;
  - Make an analysis of the future demand for Ground Tracking and Data Acquisition Facilities and maintain related Mission Model and Tracking Facilities Inventory
  - Evolve Compatible Space Communications Architectures



# IOAG Mandate As Derived From The Inter-Agency Operations Plenary (IOP)

- IOP 2 (1). The IOP charges the IOAG to continue as the international focal point for fostering and leading interoperable space communications and navigation matters for cross-support of spaceflight missions, and approves the amended IOAG Terms of Reference dated June 2007. IOAG participating Agencies should strive to comply with the IOAG's strategic guidance.
- IOP 2 (3). Furthermore, **IOAG** organizational processes should be adapted **to collect and process in a timely manner all the space communications and navigation requirements of other international space coordination groups** (e.g., the International Space Exploration Coordination Group [ISECG], International Lunar Network [ILN], and international Mars exploration, inter alia), and to provide strategic guidance to the relevant standardization organizations (i.e., the Consultative Committee for Space Data Systems [CCSDS] and the Space Frequency Coordination Group [SFCG]).



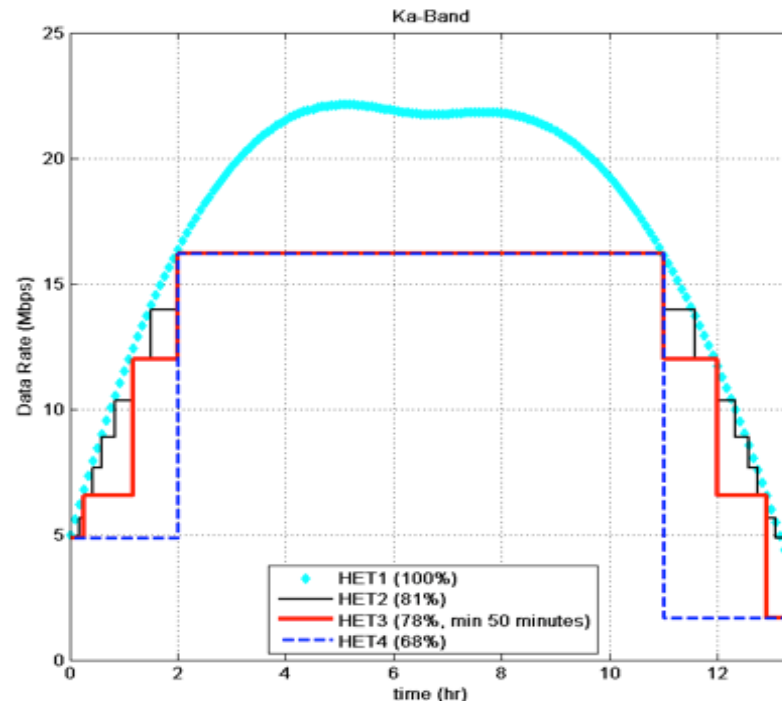
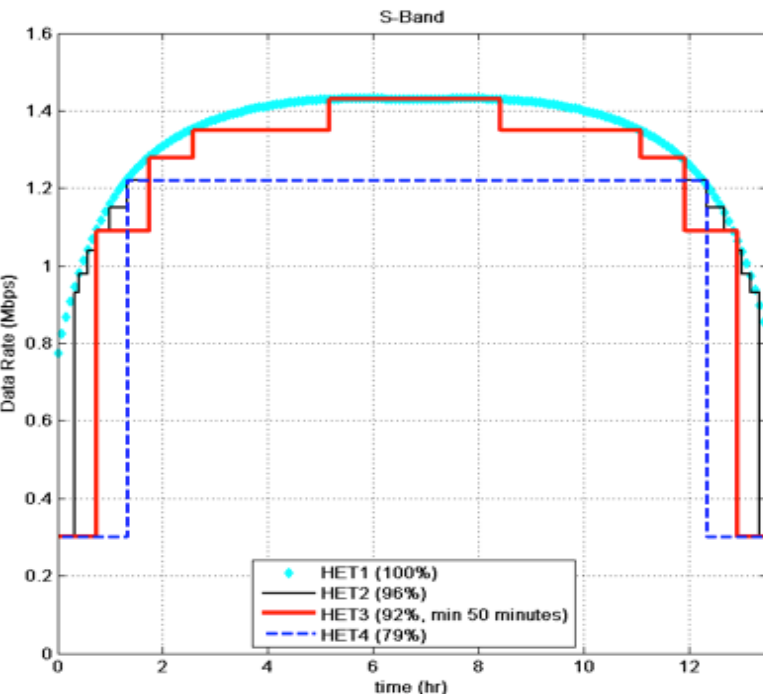
## Recent IOAG Activities That Are Relevant to ISECG

Key Activity	Results
IOAG Service Catalog	Developed the IOAG Service Catalog with definition of standard services to be implemented by the IOAG member agencies for achieving better interoperability and cross support to user missions.
Coding & Modulation	Recommended the down-selected set of coding and modulation schemes from those standardized by the CCSDS. Enabled higher degree of interoperability and further cost reduction by user missions and network assets.
Ka-Bands	Assessed and advocated the provision of 26 GHz capability to LEO missions. Some findings and techniques from this effort are applicable to Lunar and other near Earth missions.
Optical Communications	Defined the operations concept and architecture for the near-Earth optical communications. Assessed, coordinated, and advocated the optical capability infusion by the various IAG member agencies. Initiated a CCSDS standardization effort on optical links.
Space Internetworking	Defined the operations concept and architecture for the Solar Space Internet (SSI) based on the Disruption Tolerant Network (DTN) protocol suite. Initiated a CCSDS standardization effort on DTN.
Spacecraft Emergency Cross Support	Establish solutions to key problems in the current approach to providing communications support to spacecraft in emergency mode. This includes, e.g., <i>a priori licensing</i> scheme for achieving timely availability of RF licenses in time of emergency, registered global communications assets, and standard operations process/procedures (SOP) for operational interfaces.
Lunar/Mars Space Communications	Analyzed the space communications capabilities for Lunar/Mars missions of 2016-2015. Identified problems, weaknesses, and resolutions for the future.

# Moving Forward to Ka-bands

1 of 2

- High-rate data return from near Earth missions (including Lunar missions) will rely on Ka-band (26 GHz):
  - Data rates could be up to 2 Gbps with 35m ground antenna,
  - A proven capability – has been applied or soon to be applied to missions, e.g., LRO, Euclid, JWST, WFIRST, Plato, NiSAR, TESS, and ARCM,
- High-rate data return from deep space missions (including Mars missions) will rely on Ka-band (32 GHz):
  - Data rate could be up to 250 Mbps at Mars farthest distance with ground antenna array.
  - A proven capability – has been applied to or soon to be applied to missions, e.g., MRO, Kepler, Bepi Colombo, JUICE, and NeMO,



**Comparison of Data Rate Profiles: S- vs. Ka-bands for Lunar L2 Flyby case:** Shown with 4 different levels of high-efficiency tracking (HET)

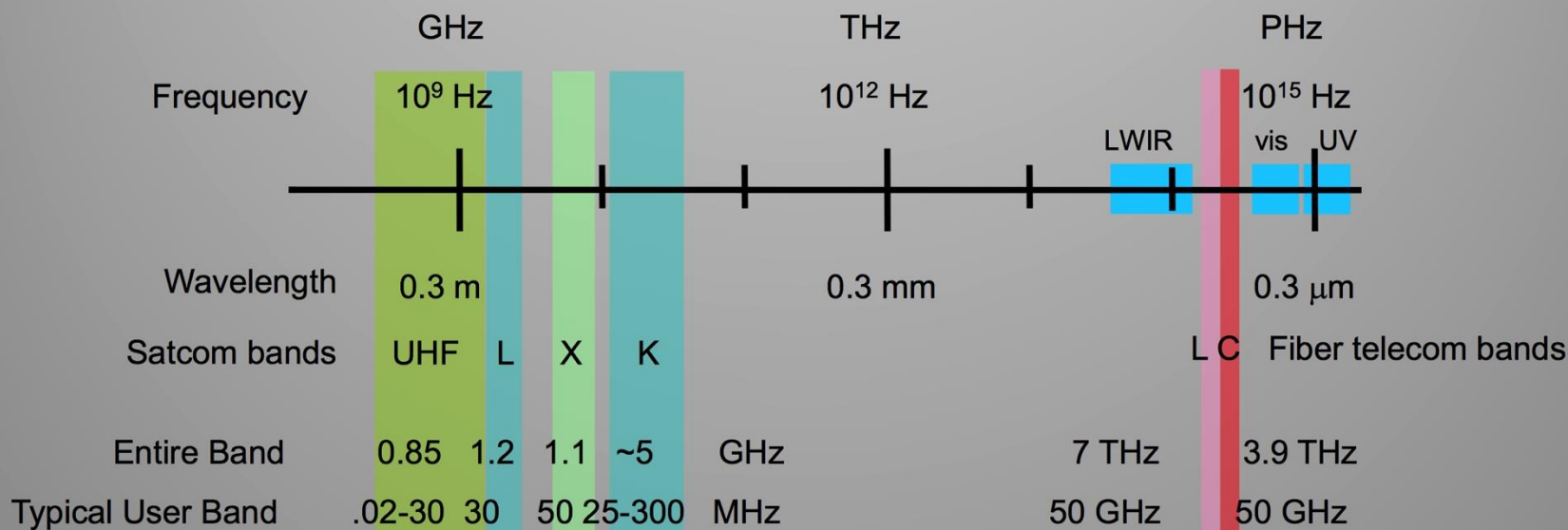
# Moving Forward to Ka-bands

2 of 2

- High-rate uplink to near Earth missions will rely on Ka-band (22 GHz):
  - Technology infusion started in ESA and NASA.
  - Will potentially be used by the NASA ARCM-1 and -2 missions.
- High-rate uplink to deep space missions using Ka-band (34 GHz):
  - In planning for human exploration to Mars,
  - Currently for radio science only, i.e., NASA's Juno and ESA's Bepi Colombo and JUICE.
- Usage of Ka-band (37/40 GHz) is under evaluation:
  - Would cover near Earth and deep space RF communication system,
  - No technology preparation yet, awaiting IOAG/ISECG advice.

# Moving Forward to Optical Communications

## Benefits of Optical Communications



Features of extremely short wavelengths of IR light	System Potential	Improvement Over RF
Nearly infinite bandwidth (and fiber telecom components to make use of it)	<ul style="list-style-type: none"> <li>- <i>Extremely high data rates</i> in <i>unregulated bands</i></li> <li>- Use of extra bandwidth to achieve very high efficiency</li> </ul>	10's of THz vs 50 GHz
Extremely high gain from small apertures	<i>Very small terminals</i>	Power delivery efficiency 10,000 <sup>2</sup> greater



# Moving Forward to Optical Communications

## Readiness of Optical Communications

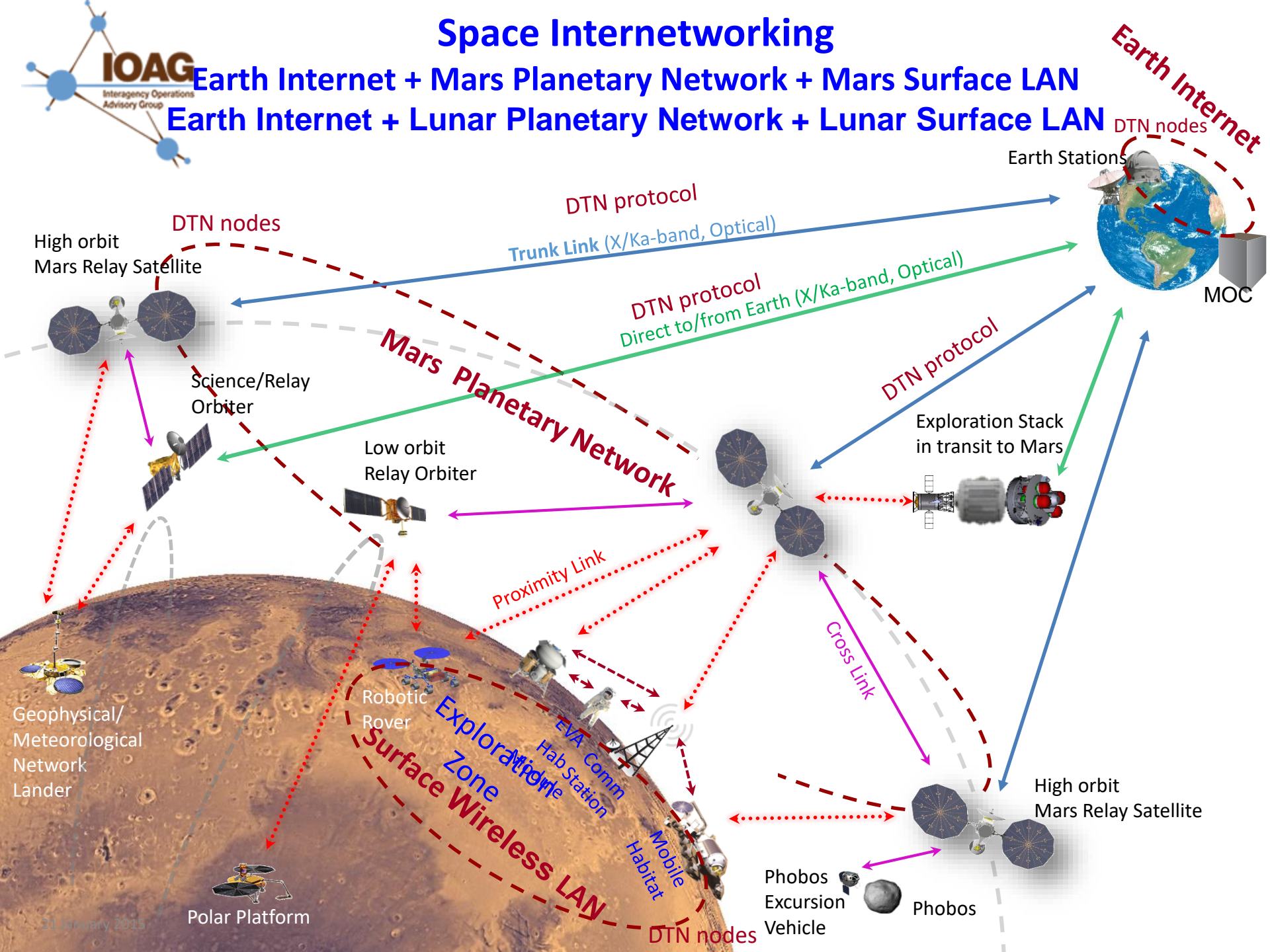
- High-rate optical downlink:
  - ~1 Gbps for near Earth and 250 Mbps for 1 AU, with pulse position modulation following the CCSDS High Photon Efficiency (HPE) standard.
  - In-Orbit Demonstrations: LADDEE (done), NASA/LCRD (in development), NASA/Psyche (decided), ESA/SWE-L5 (proposed)
    - Reduce user mission burden: e.g., allow for miniaturized terminal from Moon for Moon Rover DTE
    - Will validate deep space optical solutions to system and technological issues: e.g. reaching adequate on-board pointing through ground uplink, narrow filtering on-ground to limit background noise, need of active adaptive optics on ground.
  - Ultra high-rate return, ~10 Gbps for near Earth only, with phase modulation: not yet studied.
- Moderate-rate optical uplink: included in HPE standard.
- High-rate optical uplink: not yet studied.



# Space Internetworking

Earth Internet + Mars Planetary Network + Mars Surface LAN

Earth Internet + Lunar Planetary Network + Lunar Surface LAN





# Spacecraft Emergency Cross Support (SECS)

## The Problems

Current approach to the inter-agency emergency cross support works well, but falls short because of two inherent problems:

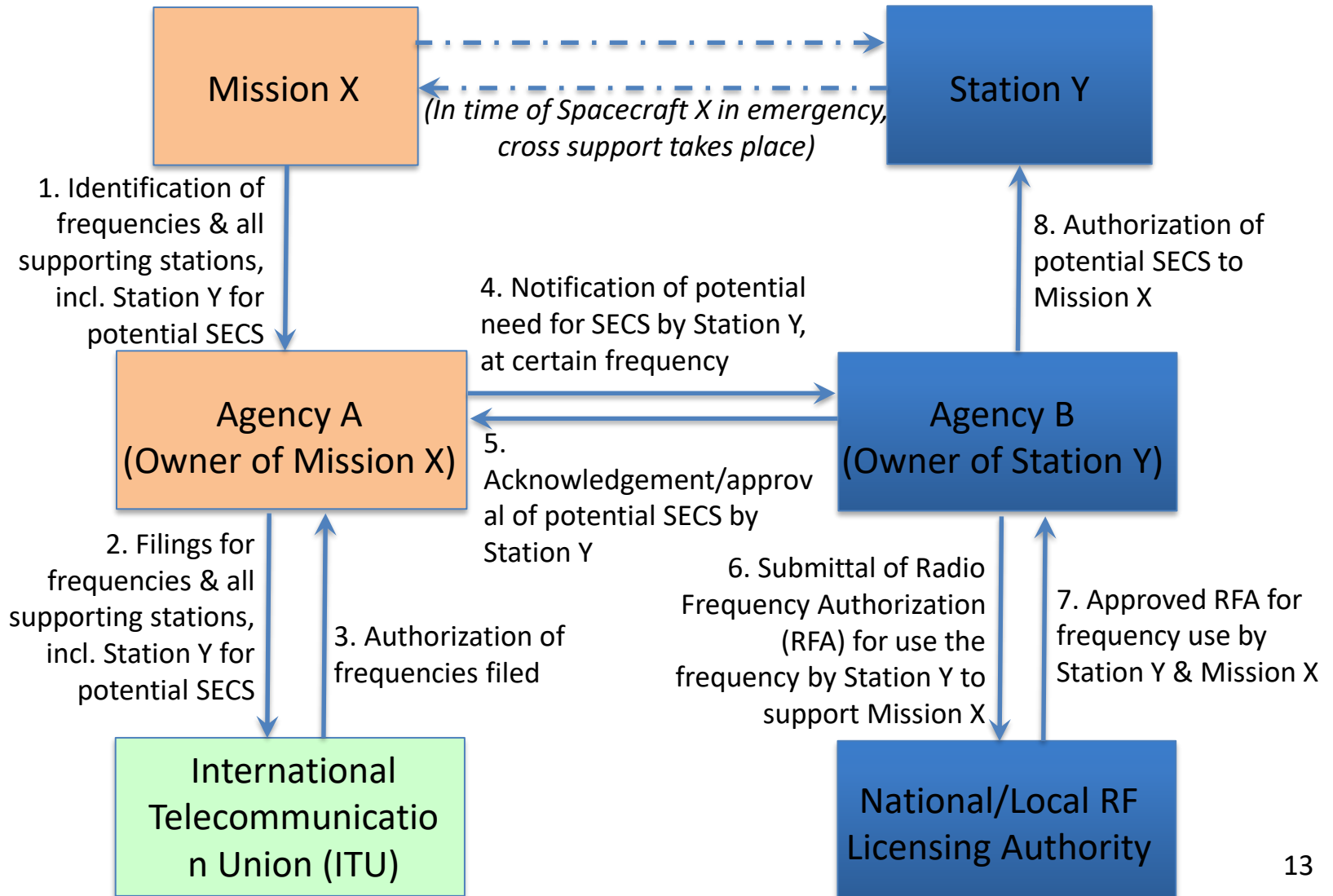
- The difficulty in achieving timely availability of uplink and downlink frequency authorizations for SECS.
- The difficulty in ensuring the SECS be conducted in an expedited, timely, and orderly manner.

## The Solutions

- Apply an *a priori licensing* scheme for achieving timely availability of RF licenses in time of SECS.
- Enlist and organize suitable, global communications assets to participate in the provision of SECS.
- Execute the Standard Operations Process/Procedures (SOP) for operational interfaces between SECS providers and users.

# Spacecraft Emergency Cross Support

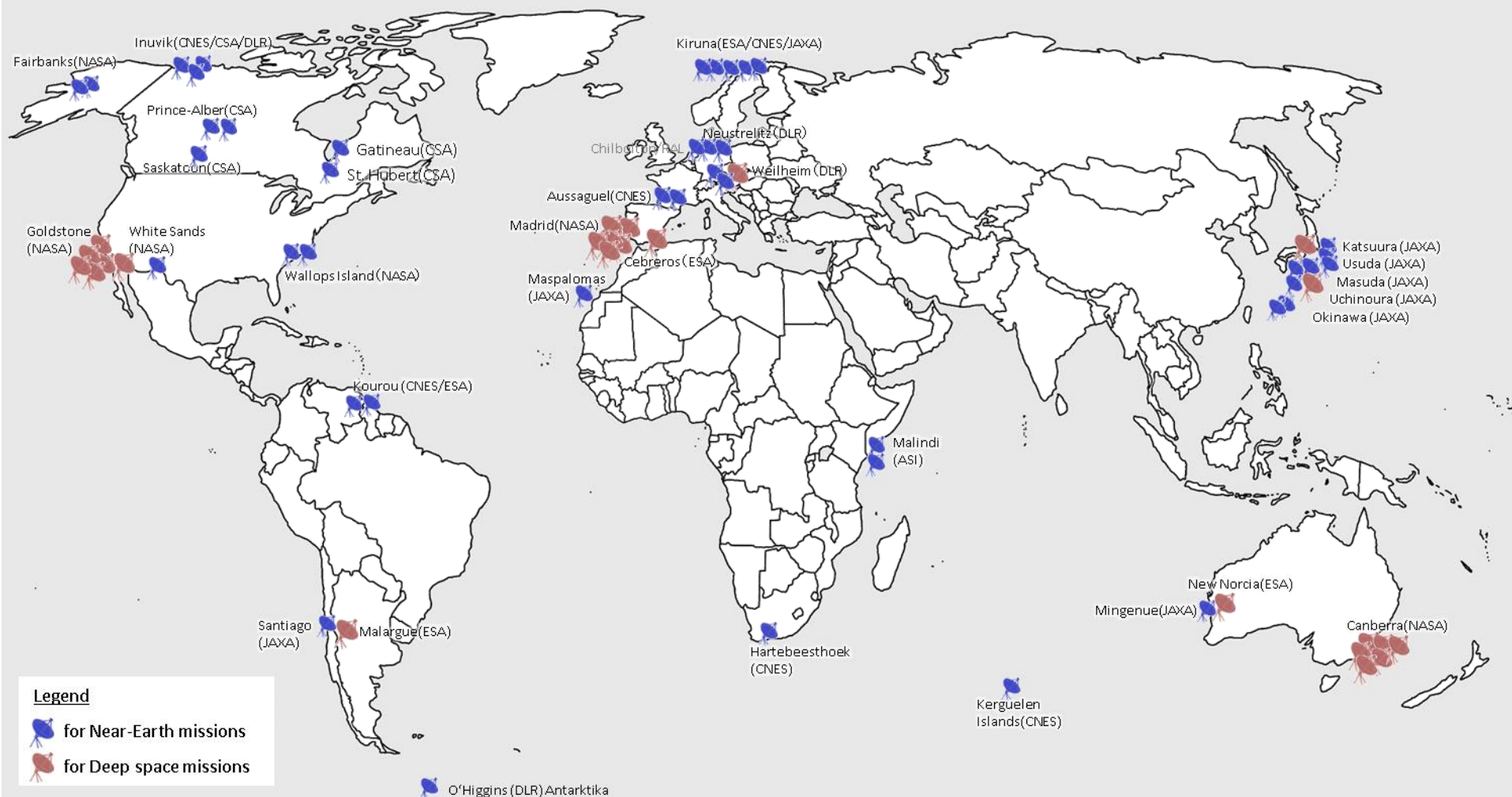
## -- Key Solution: The *a priori* RF Licensing Scheme --



# Spacecraft Emergency Cross Support (SECS)

## Key Solution: Enlisting IOAG Ground Communication Assets Available for SECS - A Global Sites Map

As of May 10, 2016





# A Conceptual Lunar Communications Architecture

Exploration Stack - The Future Context -  
preparing for trip to Mars

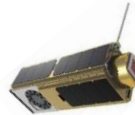


MPCV



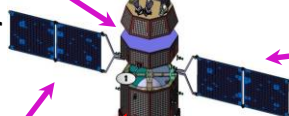
DTE/  
DFE  
links

Lunar CubeSat  
Orbiters



• Cross Link

Lunar Relay Orbiter

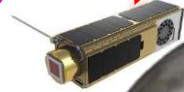


Proximity  
Link

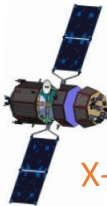
Lunar  
rover



Lunar  
lander

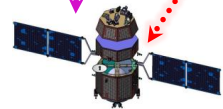


Lunar Science  
Orbiters



DTE/DFE link

X-/Ka-band, Optical



Lunar Relay Orbiter (far side)

Trunk link  
X-/Ka-bands, optical

DTE/DFE link  
X-/Ka-band

Earth GEO  
Optical relay



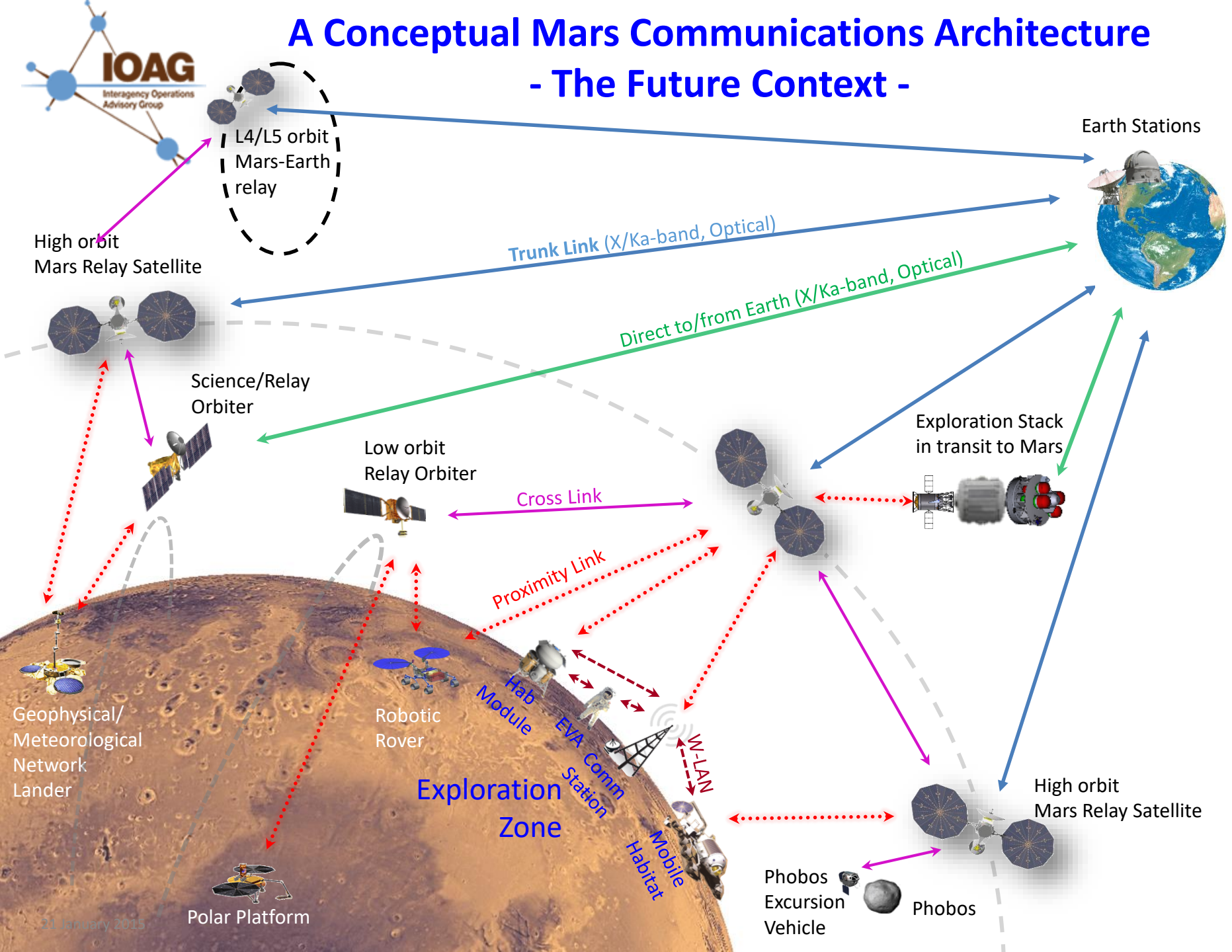
Earth  
Stations

MOC



# A Conceptual Mars Communications Architecture

## - The Future Context -





# Lunar & Mars Missions (2016-2025)

## Findings & Observations – Number of Missions

First, a few observations on the figures:

- Unprecedented number of lunar and Mars missions and space vehicles in the history of space exploration.
- Among all the missions that have decided on their cross support status, a very high percentage (~93%) of lunar missions, (~90%) of Mars missions, requires cross support. Only one mission in each domain has ruled out the need for cross support by other agencies.

IOAG Member Agencies: 8		Lunar	Mars
No. of Missions		23	15
No. of Vehicles		35	23
Cross- Supported Missions ?	Yes	16	10
	No	1	1
	TBD	6	4

# Lunar & Mars Missions (2016-2025)

## Findings & Observations – The Links

- At physical layer, near Earth X-band is gaining popularity among lunar missions, however S-band still significant. Deep space X-band is the dominant band for Mars-Earth links.
- Ka-band and/or optical links are emerging as the high-rate Mars-to-Earth links. No Ka-band and/or optical links for Earth-Moon high-rate data return – no mission requirements.
- At least 5 lunar missions will provide relay capability. However, the frequency band(s) for lunar proximity links are yet to converge. At least 8 Mars missions will provide or use proximity link. UHF-band is the dominant band(s) for Mars proximity links, i.e., for low-rate TT&C.

Frequency Bands ->	X	S	Ka	K u	UHF	Optical	TB D
Moon-Earth Uplink	12	6			1		4
Moon-Earth Downlink	16	6			1		4
Lunar Proximity Link		1	1	1	2		8
Mars-Earth Uplink	9	1					5
Mars-Earth Downlink	9	1	2			1	5
Mars Proximity Link	1				8		5

- No frequency band planned for high-rate proximity link by any lunar mission – no mission requirements. X-band and/or optical links are emerging as the higher/high-rate Mars proximity links.

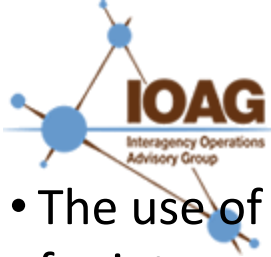


# Lunar & Mars Missions (2016-2025)

## Findings & Observations – Coding & Modulation

- Modulation schemes are all CCSDS-compliant and largely consistent with the "IOAG Report on Preferred Coding and Modulation Schemes".
  - Bandwidth efficient modulation, e.g., GMSK, has not been planned by any lunar mission, perhaps, due to no “high-rate” mission demanding high spectral efficiency.
  - Significant use of bandwidth efficient modulation, i.e., GMSK, by some Mars missions.
- Coding schemes are more confined to the traditional codes:
  - Reed-Solomon/Convolutional/Concatenated code for downlink
  - BCH code for uplink. The use of Forward Error Correction (FEC) codes for Moon-Earth uplink is happening, but not for Mars-Earth uplink.
- LDPC and Turbo codes are emerging for lunar communications. Significant use of Turbo code for Mars return link.
- The use of high-performance Forward Error Correction (FEC) for proximity link is not imminent.

Coding Schemes ->	Convolutional Code only	Concatenated (RS+Conv)	Turbo	LDPC	BCH	TBD
Moon-Earth Uplink		8	3	3		9
Moon-Earth Downlink				2	9	12
Lunar Proximity Link	2					11
Mars-Earth Uplink		7	5	1		7
Mars-Earth Downlink					7	7
Mars Proximity Link	8			1		5



# Lunar Missions (2016-2025)

## Findings & Observations - Services

- The use of standard services per IOAG Service Catalog -1 v2.0 (except Relay Services) for inter-agency cross support purpose is universally accepted by all lunar and Mars missions.
- The provision of Mars relay services (i.e. using TM/TC/AOS for the long haul and Proximity-1 for the Mars vicinity), has led to the emergence of a “rudimentary” Mars Network, which will likely persist during the decade. But, that’s not the case for lunar missions - the provision of relay services remains to be realized.
  - No obvious Lunar Network is imminent during this decade. Lunar Communications Pathfinder may be a start.

IOAG Services ->	Forward Data: FCLTU	Return Data: RAF/RCF	Radiometric Data: Validated	Delta DOR	Proximity - 1
Lunar - Compliant	13	13	9	2	2
Lunar - TBD	8	8	10		8
Mars - Compliant	10	10	7	7	8
Mars - TBD	5	5	7		5

# Lunar & Mars Missions

## Some Issues for International Collaboration

Potential issues	Remarks
Convergence of frequency bands, by future lunar missions, for lunar proximity links: low-rate TT&C links	The divergence of frequency bands for for lunar proximity links is already a phenomenon. While it does not pose a problem for cross support now, a pro-active role must be taken to prevent it from becoming a problem in the future.
Convergence of frequency bands, by future lunar/Mars missions, for proximity links: high-rate RF links	Looking ahead for future high-rate missions, containing the multiplicity of frequency bands (SFCG guidelines allow multiple choices) for better interoperability and cross support is crucial. Use 22/26 GHz bands.
Advancement to Ka-bands for high-rate RF trunk/DTE/DFE links	Looking ahead for future high-rate missions, protecting the Ka-bands (22/26, 34/32, and 37/40 GHz) from being encroached upon by G5 mobile services, use Ka-bands ASAP.
Advocacy of space internetworking services per DTN	Looking ahead for the future Lunar & Mars Networks, network layer capabilities are an essential element.
Advocacy of Cross Support Service Management (CSSM)	As CSSM standards are gradually defined, “we” may want to undertake a coordination role to plan for implementing CSSM, starting with the Simple Schedule Format.
Advocacy of optical communications	Looking ahead for future high-rate missions, “we” may want to undertake a coordination role to plan for the implementation and sharing of optical assets.



## **IOAG – ISECG Cooperation**

It is expected that the IOAG and ISECG will be involved in the future exploration/robotics missions undertaken by the various space agencies, e.g. in the case of Lunar missions (ESA's Moon Village and NASA's Cis-Lunar Transit Habitat).

In order to avoid a duplication of activities and inconsistent development of standards, communications capabilities, and network assets, either flight or ground, a close cooperation is recommended.



## IOAG – ISECG Cooperation

Among others the IOAG is dealing with the following topics that could partly be of interest to the ISECG:

- ☐ Protection of the S-band for TT&C operations of spacecraft,
- ☐ Common choices for RF Modulation and Coding in the IOAG spacecraft,
- ☐ Spacecraft Emergency Cross Support,
- ☐ Technologies for Ka-bands, i.e., 22 GHz, 34 GHz, and 37/40 GHz.
- ☐ Harmonized practices for 26 GHz band cross support utilization,
- ☐ Mission Operations Core Services,
- ☐ Disruption Tolerant Networking,
- ☐ Data Link Security Layer,
- ☐ Optical Link Communications.



# Backup Slides



# IOAG Objectives

The IOAG Work Plan 2016 responds to three overarching strategic objectives:

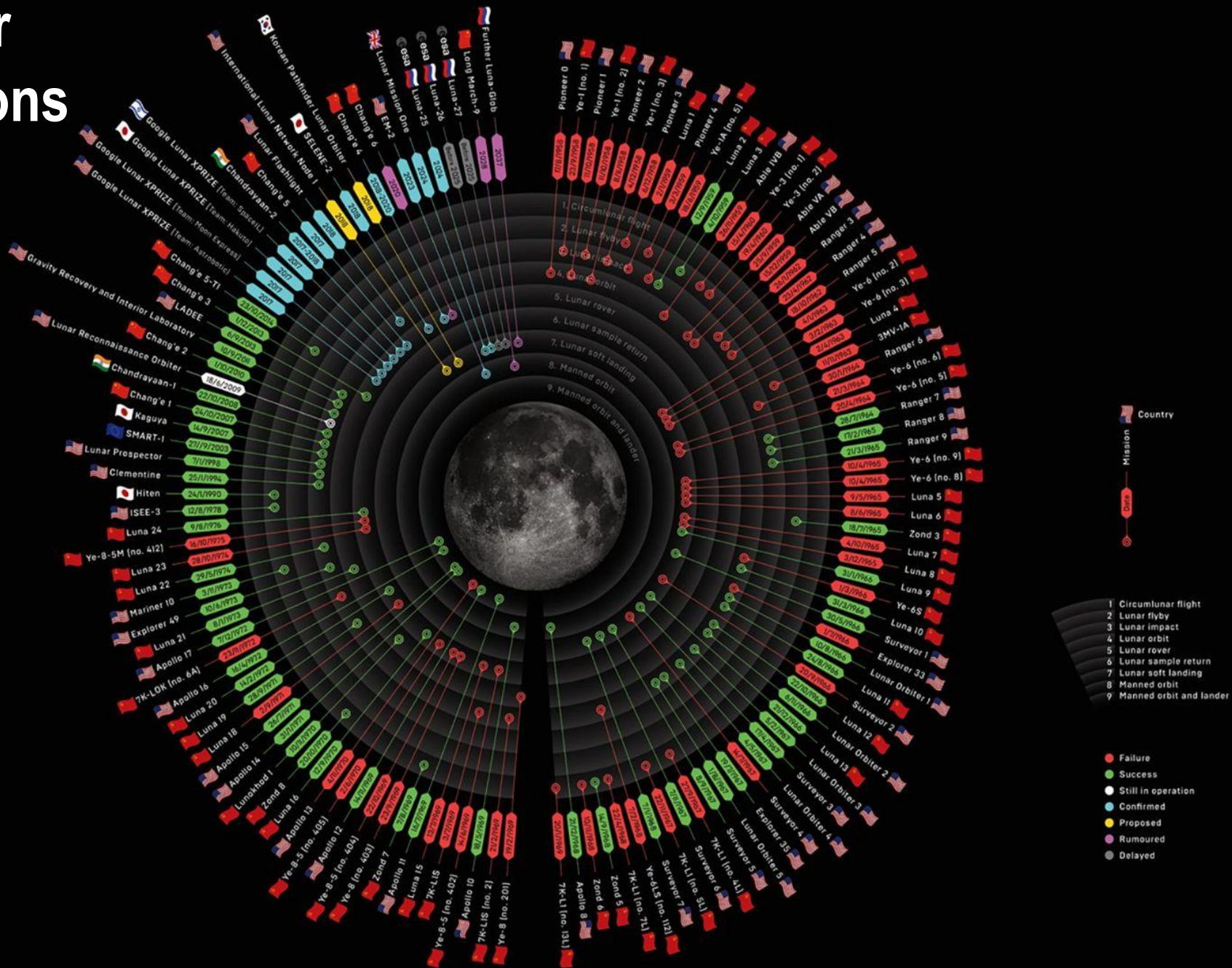
- ✓ Establish or enhance all elements of the IOAG organization required to achieve its role as the premier international focal point for matters related to cross support in the space communication and navigation domain.
- ✓ Continue effective and value added use of the IOAG in 2016 with achievements that foster the goals of IOAG and are of mutual benefit to the participating Agencies and interfacing organizations.
- ✓ Increase the visibility of IOAG by communicating its existence and purpose to relevant international groups and organizations and increase the stakeholder community.



# Working Groups

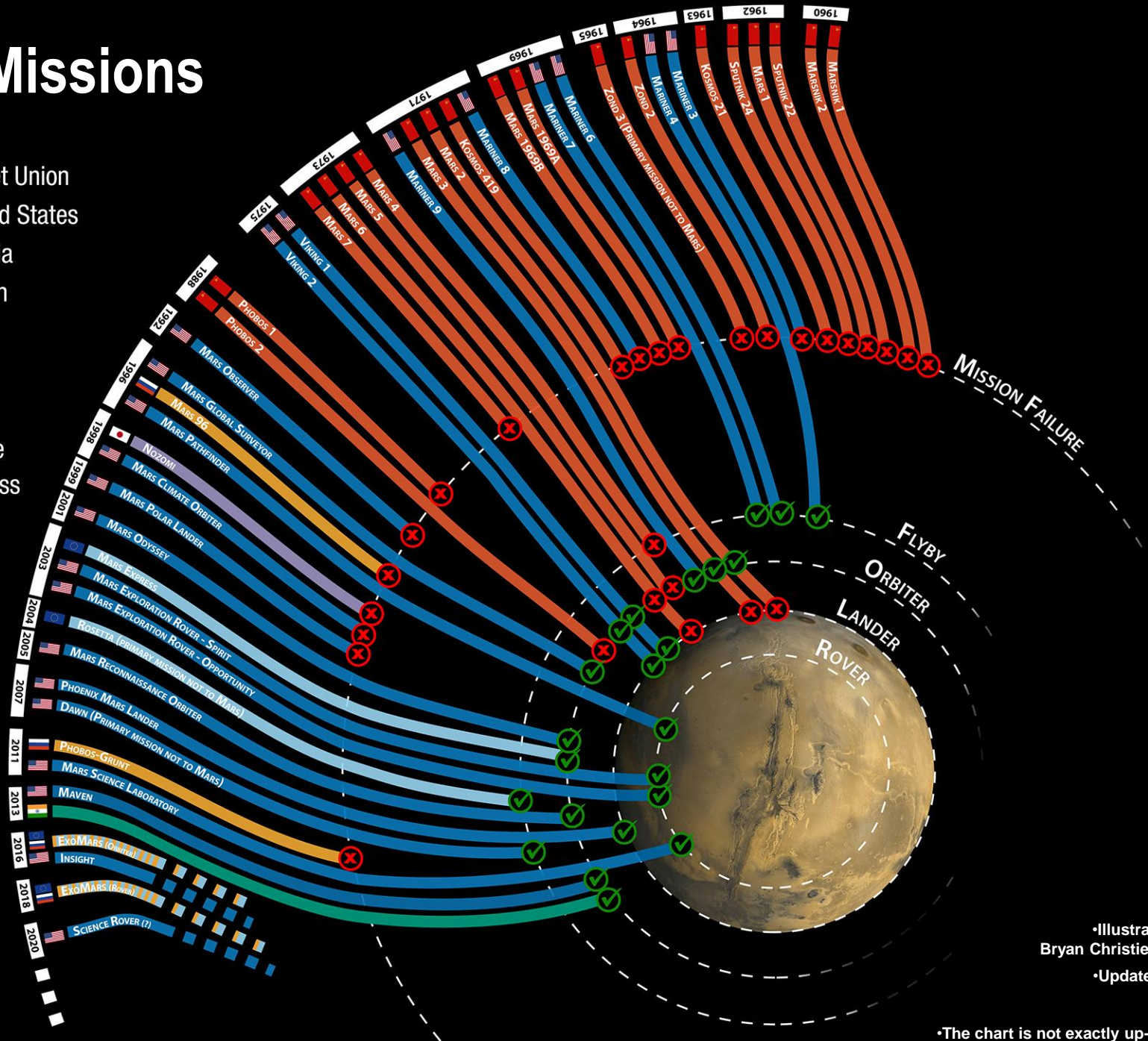
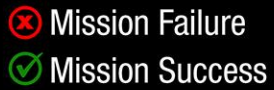
- **Coding & Modulation WG (CMWG)**  
to agree on a set of Coding & Modulation Standards
- **LEO26SG**  
to promote the utilization of the 26 GHz band for LEO missions
- **Mission Operations Systems Strategy Group (MOSSG)**  
to derive recommendations on a Strategy for Mission Operations System Interoperability
- **Optical Link Strategy Group (OLSG)**  
to follow the evolution of the optical communications
- **S/C Emergency Cross Support Working Group (SECSWG)**  
To propose guidelines for providing spacecraft emergency cross support
- **Service Catalogue WG (SCWG)**  
to maintain the Service Catalogues
- **Space Internetworking Study Group (SISG)**  
to keep track of the evolution of the space internetworking

# •Lunar Missions



•The chart is not exactly up-to-date

# •Mars Missions



•Illustration by:  
Bryan Christie Design

•Updated: 2015

•The chart is not exactly up-to-date.



# Current Lunar/Mars Missions

Lunar/Mars Missions that are currently in operational phase:

Lunar Mission	Launch Year	Agency	# of Vehicles	Mission Type
Lunar Reconnaissance Orbiter (LRO)	2009	NASA	1	Orbiter
Chang'e 3	2013	CNSA	2	Lander/rover
Mars Mission	Launch Year	Agency	# of Vehicles	Mission Type
Mars Odyssey	2001	NASA	1	Orbiter
Mars Express	2003	ESA	1	Orbiter
Mars Exploration Rover (MER) - Opportunity	2003	NASA	1	Rover
Mars Reconnaissance Orbiter (MRO)	2005	NASA	1	Orbiter
Mars Science Laboratory (MSL) - Curiosity	2011	NASA	1	Rover
Mars Orbiter Mission-1 (MOM-1) - Mangalyaan	2013	ISRO	1	Orbiter
Mars Atmosphere and Volatile EvolutionN (MAVEN)	2013	NASA	1	Orbiter
ExoMars Trace Gas Orbiter (Exo-TGO)	2016	ESA	2	Orbiter/Lander

# Lunar Missions To Be Launched During The Decade 2016 -2025

Mission	Launch Year	Agency	# of Vehicles	Mission Type
Chandrayaan-2	2017	ISRO	3	Orbiter/lander/rover
Chang'e 4	2018	CNSA	2	Lander/rover
Chang'e 5	2017	CNSA	2	Orbiter/rover for sample return
Chang'e 6	2020	CNSA	2	Orbiter/rover for sample return
KPLO	2020	KARI	1	Orbiter
Korean Lunar Mission	2020s	KARI	3	Orbiter/lander/rover
Luna 25	2024	Roscosmos	1	Lander
Luna 27	2020	Roscosmos	1	Rover
Luna 26	2020	Roscosmos	1	Orbiter
SLIM	2020	JAXA	1	Lander
Resource Prospector*	2020	NASA	2	Lander/rover
Lunar Communications Pathfinder*	2020s	ESA/SSTL	1	Relay Orbiter
Cislunar Transit Habitat*	2022	NASA	1	Orbiter
International Lunar* Exploration Precursor	2024	ESA	3	Lander/Rover/Ascender
International Human Lunar Surface Architecture*	2028	ESA	3	Lander/Rover/Ascender



# Lunar Missions To Be Launched During The Decade 2016 -2025

Mission	Launch Year	Agency	# of Vehicles	Mission Type
EM-1**	2018	NASA	1	Orbiter
EM-2**	2020	NASA	1	Orbiter
Lunar Flashlight	2018	NASA	1	CubeSat Orbiter
Lunar IceCube	2018	NASA	1	CubeSat Orbiter
Lunar H-Mapper	2018	NASA	1	CubeSat Orbiter
ArgoMoon	2018	ASI	1	CubeSat Orbiter
Omotenashi	2018	JAXA	1	CubeSat Lander
EQUILLEUS	2018	JAXA	1	CubeSat Orbiter



## Mars Missions To Be Launched During The Decade 2016 -2025

Mission	Launch Year	Agency	# of Vehicles	Mission Type
ExoMars TGO	2016	ESA	2	Orbiter/Lander
Insight	2018	NASA	1	Lander
MarCO	2018	NASA	2	CubeSat Orbiter
Red Dragon	2018	NASA/SpaceX	1	Lander
ExoMars Rover	2020	ESA	2	Rover
MOM-2	2020	ISRO	1	Orbiter
Mars Mission 2020	2020	CNSA	3	Orbiter/Lander/Rover
Emirates Mars Mission	2020	UAE Space	1	Orbiter
Mars 2020	2020	NASA	1	Rover
NeMO*	2022	NASA	1	Orbiter
Phobos-Grunt 2	2020	Roscosmos	1	Phobos sample return
HSF Pathfinder*	2024	NASA	1	Orbiter
MSR-O*	2024	NASA	2	Orbiter/SmallSat
MSR-L*	2028	NASA	2	Orbiter/SmallSat
Mars Moon eXploration (MMX)*	2022	JAXA	2	Phobos sample return